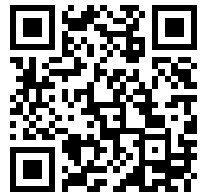

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no. 29
1922

Vol. 27, No. 27. BULLETIN, MASSACHUSETTS INSTITUTE OF TECHNOLOGY, Jan., 1922

Entered December 3, 1904, at Post-Office, Boston, Mass., as second-class matter,
under act of Congress of July 16, 1894.

Pub. Serial No. 58

**IVY
ANNEX**

PUBLICATIONS
OF THE
**Massachusetts
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22-20058



Contribution from
Electrical Engineering Research Division

Serial No. 29

January, 1922

**A MECHANICAL FREQUENCY-METER
OF TELEPHONIC RANGE**

by

Charles

A. E. Kennelly and C. H. Manneback

UNIVERSITY OF VIRGINIA



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A MECHANICAL FREQUENCY-METER OF TELEPHONIC RANGE.*

BY

A. E. KENNELLY, Sc.D.

Member of the Institute.

and **CH. MANNEBACK.**

IN the JOURNAL OF THE FRANKLIN INSTITUTE for May, 1919, Dr. L. V. King described and illustrated a form of mechanical frequency-meter which he called a "sonometer." His illustration of the device is reproduced in Fig. 1, ACB is a fine steel wire fastened at one end to the top of the cathetometer and soldered at the other end to a known weight $W + W$. This wire is supported in front of a telephone electromagnet T energized by the alternating current whose frequency is to be determined. The position of the bevel edge C is adjusted until, with the electromagnetic T excited, the wire BC is set into resonant vibration. The frequency of the exciting current is then

$$f = \frac{1}{2l} \sqrt{\frac{T}{m}} \quad \frac{\text{cycles}}{\text{sec}} \quad (1)$$

where T is the total tension on the wire in dynes.

m— the linear mass of the uniform wire in gm/cm.

l— length of the vibrating segment BC in cm.

DESCRIPTION OF THE FREQUENCY-METER.

The laboratory frequency-meter here to be described is a development of the King sonometer, undertaken in the electrical engineering laboratories of the Massachusetts Institute of Technology.

In the King sonometer described, the linear mass was 1.373 gm/cm., and the available range of frequency was 360 to 1600 cycles per second.

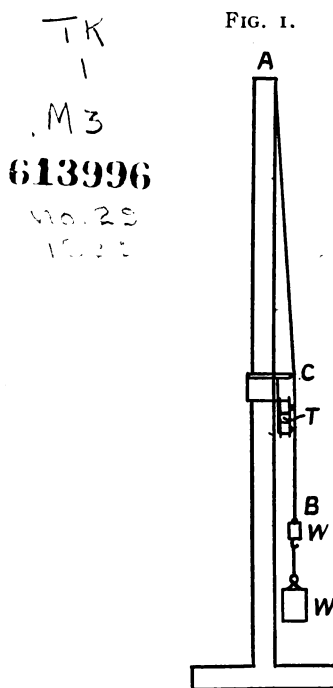
The final form of the instrument is shown in Fig. 2. The wire used was a silver-plated steel wire, known as a "black diamond" string or "guitar B" as furnished by the National Musical Co., of New Brunswick, New Jersey, having a diameter of 0.350 mm.

* Communicated by Dr. Kennelly.

which was entirely uniform over the length used, so far as ordinary micrometer measurements showed. Its linear mass was 7.585 gm/cm., as a mean of three determinations in close agreement.

The length of wire in the vibrating segment can be varied between 3 cm. and 60 cm., over a working range of from 250 to 2500 cycles per second.

A rectangular brass bar CD, Fig. 2, 60 cm. high, 2.5 cm. wide and .83 cm. thick, was graduated to a millimeter scale of length.

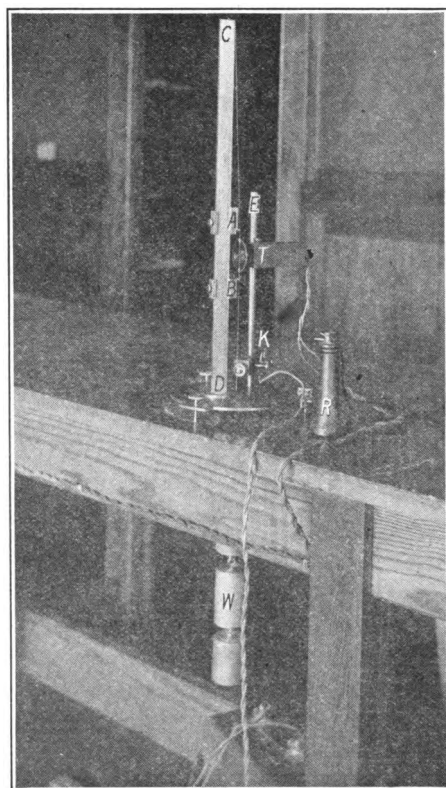


This vertical bar is supported on a flat circular brass base plate, 6.4 mm. thick and 250 mm. in diameter. This plate is, in turn, supported by three ordinary brass leveling screws, passing through projections at the edge of the plate. The bar is soldered to a small brass disk, 6.4 mm. thick and 55 mm. in diameter, which is fastened by screws to the base plate. The base plate also supports the vertical brass rod, which serves to carry the operating telephone T, mounted in a wooden frame at an adjustable height approximately half way between the bevel edges A and B. In practice, the height

of this telephone T does not have to be varied, and, in any future similar instrument, might be left fixed.

A rack and pinion screw, on the frame of the telephone T, enables the horizontal distance between the telephone poles and the vertical wire to be conveniently adjusted. The cover and diaphragm

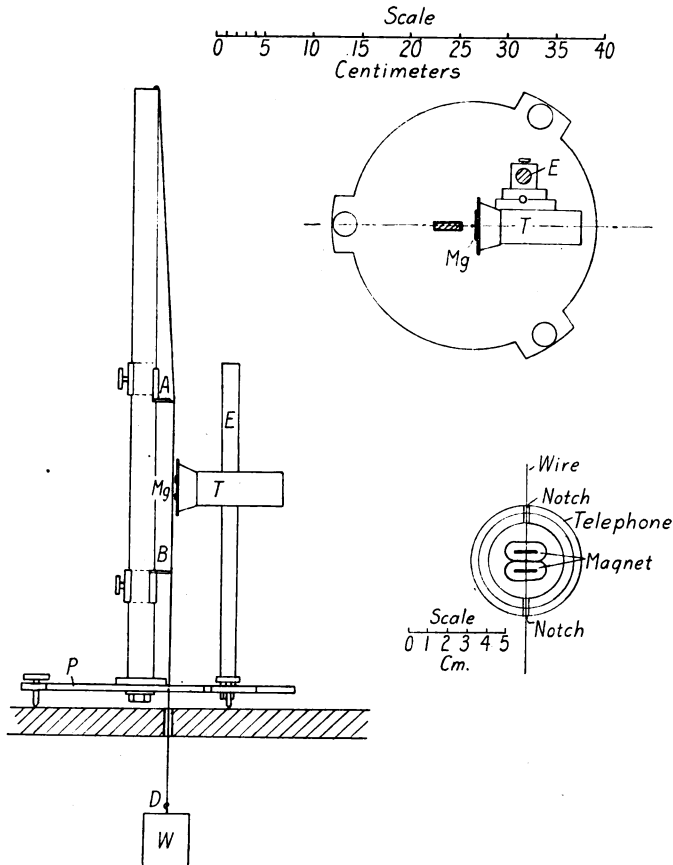
FIG. 2.



of this telephone are removed. The metallic lip has a notch in it above and below, to permit the poles to approach the wire closely. The magnet of the telephone might be removed from its frame, as in the King sonometer, but the usual composition case affords a convenient mechanical protection. The poles should occupy the horizontal positions shown in Fig. 3, and no advantage has been found to attend any other position of these poles with respect to

the wire. The vertical steel wire tends to close the magnetic circuit of the telephone in the same manner as though it were a central strip cut from the ordinary diaphragm. At low frequencies, with long vibrating wire segments, the distance from poles to wire may

FIG. 3.



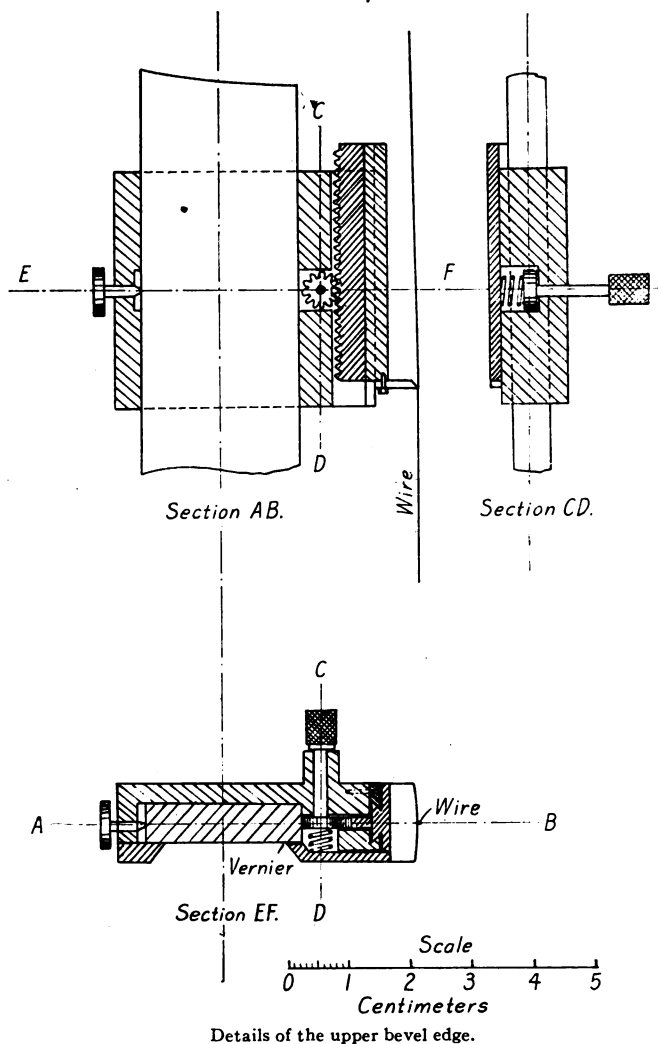
Mechanical measurement of the frequencies.

be 2.5 mm., to allow of free vibration; but at high frequencies, with short vibrating segments, the distance may be reduced to 0.5 mm., or less.

The lower brass bevel edge B has a simple sliding motion on the vertical bar, with a clamp screw to hold it in place. The upper brass edge A has, in addition to a clamp screw, a rack and pinion

vernier adjustment, as shown in Fig. 4. Final adjustments of the length to the vibrating wire segment are effected easily to a tenth

FIG. 4.



millimeter at this vernier pinion screw. For convenience of reading the millimeter scale, the vertical rod has an arbitrary zero at a point about 20 cm. above the base. From this zero, the scale numbers

increase in each direction, so that the total length of the vibrating wire segment is always the numerical sum of the two bevel-edge readings. If this arrangement were not employed, the reading of the lower edge would have to be subtracted from that of the upper edge.

The steel wire is allowed to pass through a hole in the base plate, and also through a similar hole in the table. Beneath the table, the weight or weights W are suspended from the wire in the ordinary way. Fig. 3 gives drawings of the instrument in plan, and in side elevation.

METHOD OF USE.

The telephone T , Figs. 2 and 3, has its terminals connected to the source of alternating current to be tested. The particular telephone used has a direct-current resistance of 86 ohms and is a Western-Electric instrument of a standard type. At a frequency of 2000 ω , an impressed e.m.f. of 5 volts rms. at telephone receiver terminals, produced a current of about 8.75 milliamperes, representing an impedance in the receiver of about 570 ohms.

In order to form an idea of the magnitude of the frequency to be measured, it is convenient to lay the diaphragm on the receiver, so as to hear the pitch of the sound emitted. This preliminary test also shows that the receiver is in operative condition. A rough estimate of the frequency can thus be made by ear. Reference to a calibration chart for the instrument will then show what distance between bevel edges AB may be looked for with a given suspended weight W . If the frequency is low, say below 500 ω , the distance AB will be fairly large (at least 100 mm. with 900 gm.), and mechanical resonance is then easily detected as soon as the right distance AB is found, by the bowing of the wire into a ventral segment, as well as by its emitted sound. From the measured distance AB , and the applied weight W , the frequency can then be read from the calibration chart.

If the frequency to be measured is much above 500 ω , the distance AB must be reduced. Thus at 2500 ω , the distance AB becomes 52.5 mm. with a total weight of 5.4 kg. In such a case, the poles of the receiver T may have to be brought close up to the wire and the amplitude of resonant vibration is small. In a quiet room, the point of resonance can still be detected by sound, but the amplitude of vibration may escape notice, depending on the exci-

tation of the receiver. In a noisy room it may be necessary to use an auxiliary indicating device, and it is often convenient to use the latter, even under favorable conditions of measurement.

AUXILIARY DEVICE.

Various devices for indicating mechanical resonance have been tried. A very satisfactory device is found in a carbon microphone button, brought into contact with the wire below the bevel edge B, and therefore outside the principal vibrating segment. A unidirectional current of a few milliamperes is passed through the microphone button and a head telephone from a local 4-volt storage battery. In Fig. 2, however, an auxiliary hand telephone R is shown. The auxiliary receiver R reproduces in the ear of the observer, the tone of the exciting telephone receiver T. When mechanical resonance is attained, by securing the proper distance AB between bevel edges, the auxiliary telephone gives a clearly distinguishable loud tone; so that it is only necessary to separate the edges A and B slowly, starting both from their zero or coincidence position, to recognize resonance in the auxiliary receiver R. The microphone button is supported on the end of a flexible spiral spring, which, in turn, rests in a wooden block on the upright brass rod E. The contact between the button and the wire is normally so light that no appreciable change occurs therefrom in the tension of the wire.

CALIBRATION OF THE FREQUENCY-METER.

The instrument was calibrated in two ways, namely, (1) by measuring the rotary speed of the alternator supplying the telephonic frequency, (2) by measuring the frequency delivered to the telephone T with an electric bridge.

Fig. 5 shows an electrically driven stroboscopic fork,¹ mounted in front of a disk target carried by the rotor of the alternator diverting the frequency to be measured. The fork F can be adjusted in frequency, and in vibration, over a range of about 10 per cent., with the aid of the pulleys P and sliding weights S. This fork, in turn, had its calibration checked with the aid of speed

¹ "The Measurement of Rotary Speeds of Dynamo Machines by the Stroboscopic Fork" by A. E. Kennelly and S. Whiting, *Proc. A.I.E.E.*, June, 1908, p. 631.

counters. Fig. 6 is a calibration diagram, drawn on logarithm paper, with the frequency as ordinates, against the distance between bevel edges as abscissas, for five different values of the suspended weight. These give five parallel straight lines computed according to the formula

$$f = \frac{1798}{l} \sqrt{W} \quad \text{cycles/sec.}$$

where l is the bevel-edge distance expressed in millimeters, and W is the suspended weight in grams. The actual calibration agreed substantially with these straight-line graphs, although the observations deviated occasionally to one side or the other. Higher frequencies and shorter bevel-edge distances call for heavier weights, while, on the contrary, the smaller weights should be used with the lower frequencies. Consequently, assuming that the proper weight is used, the frequency is read off the corresponding straight-line graph in Fig. 5.

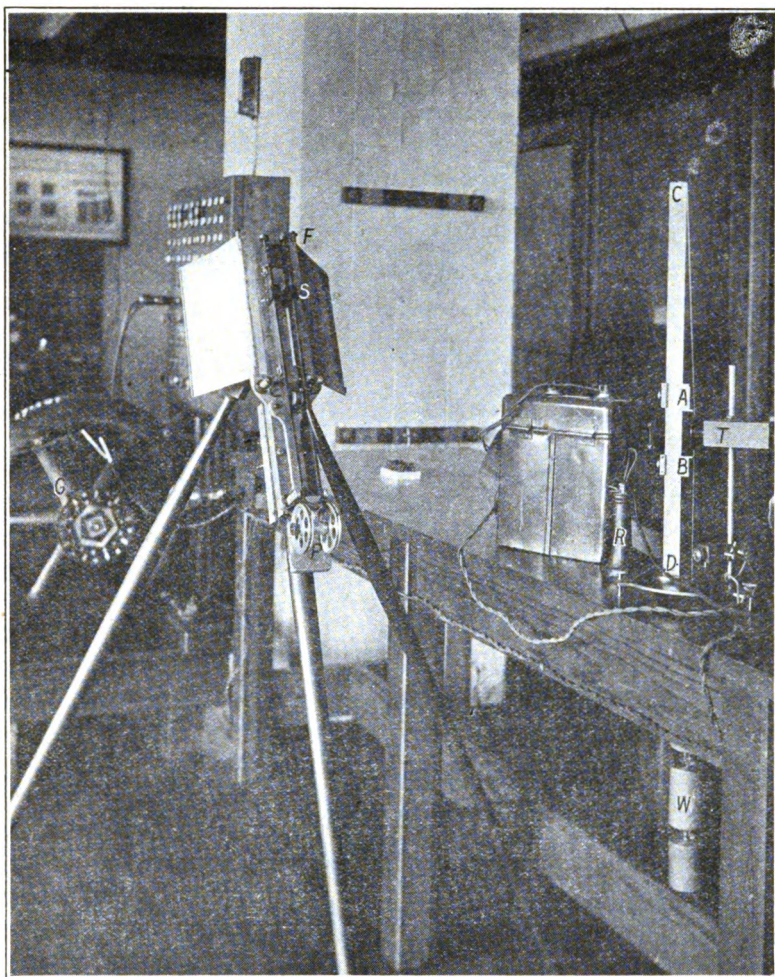
PRECISION.

The instrument is so sensitive to frequency, as was pointed out by Doctor King, that a bevel-edge setting can be adjusted and read ordinarily to one-tenth of a millimeter. If the bevel-edge distance was say, 10 cm., this would correspond to a nominal precision of 1 per mil. of the measured frequency. Owing, however, to certain errors in the instrument, the actual precision attainable has been distinctly less, and under favorable weight conditions, the actual deviation of a single observation was sometimes 1.5 per cent., or an error 15 times larger than that estimated by adjustment of length. It would appear that the error of observation, as that term is ordinarily understood, is small and rarely exceeds 2 or 3 per mil.; whereas systematic errors inherent in the construction used, attain 10 or 15 per mil. (1 to 1.5 per cent.), assuming that favorable weights are retained. If unsuitable weights are employed, the errors may be still greater.

It is supposed that the systematic errors here referred to are due to deviations of the actual nodal point from the bevel edges. In other words, if the vibrating wire formed its nodal points exactly at the bevel edges, these systematic errors might vanish.

directed toward eliminating these systematic errors, so as to increase the available precision.

FIG. 5.



ADVANTAGES OF THE INSTRUMENT.

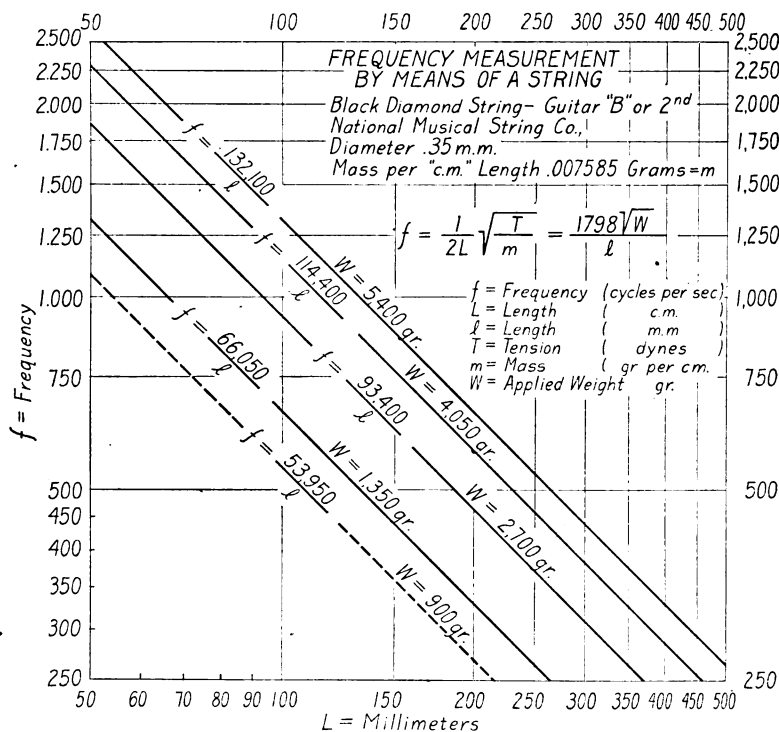
(1) The instrument is easily constructed. Although the form described is not very portable, it is well adapted to telephone laboratory use, and is not likely to get out of order.

(2) The instrument enables a frequency measurement to be made very swiftly.

(3) Very small power is consumed.

(4) It has been shown experimentally that the measurements are but little affected by wave shape of the current whose frequency is determined.

FIG. 6.



(5) Large available frequency range. The instrument here described covers a tenfold range.

DISADVANTAGES.

(1) Owing to the numerous possible nodes of vibration of a monochord, care must be exercised to measure the fundamental frequency, and not to be misled by mechanical overtones.

(2) Proper weights should be used with the instrument, in

accordance with the frequency to be measured. In the instrument described the recommended weights are as follows:

Frequency Cycles per second	Best weight Grammes
250 to 500	900
500 to 750	1350
750 to 1250	2700
1250 to 1750	4050

In the calibration of any particular instrument of this type, the best weights to use can readily be determined experimentally.

The authors desire to acknowledge their indebtedness, not only to Prof. L. V. King for the original idea of the instrument, but also to Prof. V. Bush, and to Prof. F. S. Dellenbaugh of our department, for help and valuable suggestions.

LIST OF RESEARCH BULLETINS

Bulletin
Number

- *1. The Economical Transportation of Merchandise in Metropolitan Districts. H. Pender and H. F. Thomson; March, 1912.
- *2. Notes on the Cost of Motor Trucking. H. Pender and H. F. Thomson; October, 1912.
- *3. Observations on Horse and Motor Trucking. H. Pender and H. F. Thomson; March, 1913.
4. Relative Fields of Horse, Electric and Gasoline Trucks. H. F. Thomson; August, 1914.
- *5. The Delivery and Handling of Miscellaneous Freight at the Boston Freight Terminals. H. Pender, H. F. Thomson, and C. P. Eldred; February, 1914.
6. The Delivery System of R. H. Macy & Co. of New York. H. F. Thomson, H. L. Manley and A. L. Pashek; September, 1914.
7. Explorations over the Vibrating Surfaces of Telephonic Diaphragms under Simple Impressed Tones. A. E. Kennelly and H. O. Taylor; April, 1915.
8. The Mechanics of Telephone-Receiver Diaphragms as Derived from their Motional-Impedance Circles. A. E. Kennelly and H. A. Affel; November, 1915.
9. Experimental Researches on Skin Effect in Conductors, A. E. Kennelly, F. A. Laws and P. H. Pierce; September, 1915.
10. Tractive Resistances to a Motor Delivery Wagon on Different Roads and at Different Speeds. A. E. Kennelly and O. R. Schurig; June, 1916.
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26. Induction Motor Core Losses. P. L. Alger and R. Eksergian, February, 1921.
27. Acoustic Impedance and Its Measurement. A. E. Kennelly and K. Kurokawa, February, 1921.
28. A Simple Harmonic Analyser. V. Bush; Electromechanical Device for Rapid Schedule Harmonic Analysis of Complex Waves. Frederick S. Dellenbaugh, Jr.; Alignment Chart for Circular and Hyperbolic Functions of a Complex Argument in Rectangular Coördinates. V. Bush, January, 1922.
29. A Mechanical Frequency-Meter of Telephonic Range. A. E. Kennelly and C. H. Manneback, January, 1922.